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ADAPTION OF THE AN/GPA-98A COUNTER-
MEASURES SIGNALS SIMULATOR FOR USE
WITH THE AN/UPS-1 RADAR SET

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THESIS

ADAPTATION OF THE AN/GPA-98A COUNTERMEASURES
SIGNALS SIMULATOR FOR USE WITH
THE AN/UPS-1 RADAR SET

by

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by

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ABSTRACT

The AN/GPA-98A countermeasures signals simulator is intended for use with Air Force radars to provide simulated electronic countermeasures signals for radar operator training in an ECM environment. It is capable of simulating two independent aircraft targets with associated ECM -- pulse jamming, chaff, and high duty cycle AM/FM jamming.

The purpose of the study was to determine the modifications to adapt the simulator for use with the AN/UPS-1 air-search radar located at the Naval Postgraduate School radar laboratory. Signals required by the simulator from the radar were determined, the radar and simulator were modified, and interconnections were made. Upon solution of several minor problems, the simulator was aligned and signal levels were adjusted for proper operation with the AN/UPS-1 radar.

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I. INTRODUCTION

The AN/GPA-98A Countermeasures Signals Simulator was designed for use at U. S. Air Force radar sites to provide Electronic Countermeasures signals for radar operator training in an ECM environment [Ref. 1] . It is capable of simulating two independent aircraft targets with associated ECM--pulse jamming, chaff, and high duty cycle AM/FM jamming. The simulated signals are introduced at the RF input of the radar either separately or in conjunction with normal received signals. This provides realistic inputs which can be used to demonstrate the effects of the various types of ECM and the effectiveness of different ECCM techniques.

An AN/GPA-98A simulator was obtained by the Naval Postgraduate School for use in the radar laboratory. An estimate of $15,000 was received from a commercial firm to conduct an engineering study to determine the interfacing required to utilize the simulator with radars available in the radar laboratory. However, it was decided that the task would be appropriate for a student thesis project.

The purpose of this project was to determine the modifications and interfacing required to utilize the simulator with two air-search radars in the NPS radar laboratory, the AN/UPS-1 and AN/SPS-40A. The first of these is a transportable air-search radar used by the Marine Corps which

operates in the lower D-band (S-band) and has a coherent MTI capability. The second is a ship-borne long-range air-search radar operating at UHF and employing pulse compression in addition to an MTI capability.

Although the countermeasures simulator is not specifically designed for use with either radar, it was determined that adaptation for use with the AN/UPS-1 radar would require a minimum amount of modification to the radar and simulator. In order to become familiar with the simulator, it was decided to first adapt it for use with the AN/UPS-1 and then determine the additional modifications necessary for adaptation to the AN/SPS-40A.

Signals required by the simulator from the AN/UPS-1 radar were determined, the AN/GPA-98A was set up, modifications and connections made, and the simulator aligned and adjusted for proper operation. A large fraction of the available time was devoted to troubleshooting and aligning the simulator, so the project was terminated upon successful interfacing of the simulator and AN/UPS-1 radar.

II. DESCRIPTION OF EQUIPMENT

A. DESCRIPTION OF AN/GPA-98A COUNTERMEASURES SIGNALS SIMULATOR

The Countermeasures Signals Simulator, AN/GPA-98A, consists of a simulator group console and from one to three converter groups, each of which interfaces the console with an associated radar. The console can generate two simulated targets with associated ECM emissions consisting of pulse jamming, chaff, and high duty cycle AM/FM jamming. The signals corresponding to the simulated targets and their ECM emissions are generated at 30 MHz or 5-6 GHz intermediated frequencies. The simulated targets and ECM are applied to the RF input of the associated radar through its converter which heterodynes the IF frequencies to the radar carrier frequency. The total volume of the equipment is equivalent to approximately two standard six-foot racks.

1. Target Generation

Each simulated target generated in the console consists of phase-coherent 30 MHz pulses which are shifted 180 degrees in phase from sweep to sweep to simulate a maximum doppler phase shift for coherent MTI radars. The pulse width is the same as that of the radar. The pulse amplitude is modulated to simulate the effects of changes in target cross section, range, relative azimuth and elevation, and of chaff masking. The target radar cross section, speed, rate

of turn, altitude, and initial position and heading are set manually at the console which then continuously generates target range, azimuth and elevation information. Amplitude and timing of target signals are automatically changed to simulate motion of aircraft and chaff clouds.

2. Pulse Jammers

Two pulse jammers are provided on the console. Each is independently controlled and may be assigned to either target. There are four modes of operation: Spoof, Asynchronous, Repeat, and Repeat-Off-Frequency. Coherent or noncoherent pulses may be selected in all modes except Repeat-Off-Frequency. The pulse widths may be controlled manually.

In the Spoof mode, jamming pulses are generated on each range sweep within certain azimuth sectors. The widths of the sectors and spacing between sectors is symmetrical and may be varied manually. The range density or spacing of the jamming strobe is different in each consecutive sector. However, the pulses are synchronized with the target pulse so that one of the jamming pulses is coincident with the target pulse on each sweep. The average range density or spacing of the jamming strobes may be controlled manually. In the asynchronous mode, jamming pulses are present on all range sweeps and are not synchronized with the target pulses. The range density may be controlled manually. In the Repeat and Repeat-Off-Frequency modes of operation, a single jamming pulse is generated at the target range on each range sweep.

In the Spoof, Asynchronous, and Repeat modes, the 30 MHz IF frequency of the pulse jamming may be either the basic 30 MHz IF that is also used for the target pulse or a separately generated noncoherent 30 MHz IF. In the Repeat-Off-Frequency mode, the IF is generated by a 32 MHz oscillator. In all modes the jamming pulses are generated continuously and are amplitude modulated as a function of a manually set jammer power control, the associated target range, relative elevation antenna pattern, and relative azimuth antenna pattern. An antenna pattern INVERT is provided which replaces the relative azimuth antenna pattern with a fixed gain at all azimuths to simulate inverted-antenna-pattern or inverse-gain jamming.

3. Chaff Simulation

The chaff generation circuits develop IF signals representing chaff drops from either or both simulated targets. Drop rates can be programmed automatically for from one drop per radar revolution to one drop every eight revolutions. Drops may also be initiated manually every revolution. The chaff circuits also generate a chaff masking signal which attenuates simulated targets appearing at the same or greater range and at the same azimuth as the chaff.

Two modes of drops are provided: bundles which can be dropped manually each radar antenna revolution or at programmed rates, and clouds which produces the effect of a continuous drop. Once the chaff has been dropped, it drifts and blooms in accordance with manually set wind direction,

speed, and shear bloom rate. The IF spectrum of the simulated chaff signals is derived from a phase coherent 30 MHz signal by amplitude and phase modulating the 30 MHz signal with a random 40 kHz signal whose amplitude is proportional to the radar frequency, wind speed, and shear. The chaff IF is then amplitude modulated as a function of manually set chaff density, range, and a low frequency noise signal which simulates the randomly varying reflectivity of the chaff.

4. Multijammers

Two high duty cycle multi-mode jammers (multijammers) are provided on the console. Each is independently controlled and may be assigned to either simulated target. The multijammer has four modes of operation: CW, AM, FM, and BARRAGE. In the CW mode, the multijammer provides a CW signal continuously tunable from 5 GHz to 6 GHz. In the AM mode, the 5-6 GHz IF is amplitude modulated by a 5 MHz bandwidth noise signal. In the FM mode, the 5-6 GHz IF is frequency modulated by either the 5 MHz bandwidth noise signal or a variable frequency triangular waveform of from 10 Hz to 5 MHz. The frequency deviation is manually controlled from zero to 400 MHz. In the BARRAGE mode, the 5-6 GHz IF is simultaneously modulated as in the AM and FM modes. In all modes the power output of the multijammer is modulated in proportion to computed target range, selected power level, and relative elevation and azimuth antenna patterns.

5. Antenna Pattern Generation

The purpose of the antenna pattern generation circuits is to provide analog voltages to simulate the effects on the signals of the radar antenna pattern in azimuth and elevation. This is accomplished through the use of a mechanically driven antenna pattern disk, light source, and photo cell (Figure 1). The antenna pattern to be simulated is imprinted as an opaque pattern on a transparent plastic disk. The disk is driven by a mechanical differential whose inputs are antenna and target azimuth for the azimuth pattern generator, and antenna and target elevation for the elevation pattern generator. The light striking the photocell is proportional to the length of the slit uncovered by the pattern. The photocell current is amplified by the DC photocell amplifier to provide a voltage which is approximately a linear function of the antenna gain (Figure 1). This analog voltage is then applied to the target, chaff, and jamming generation circuits to modulate the IF outputs as a function of the antenna pattern attenuation and the relative azimuth (or elevation) between the antenna and the target. The gain of the modulator drivers is so designed that the analog voltage results in a signal attenuation of either 2.5 dB per volt or 5 dB per volt, simulating either one-way or two-way antenna patterns, depending on whether radar echo or jamming transmitter is being simulated.

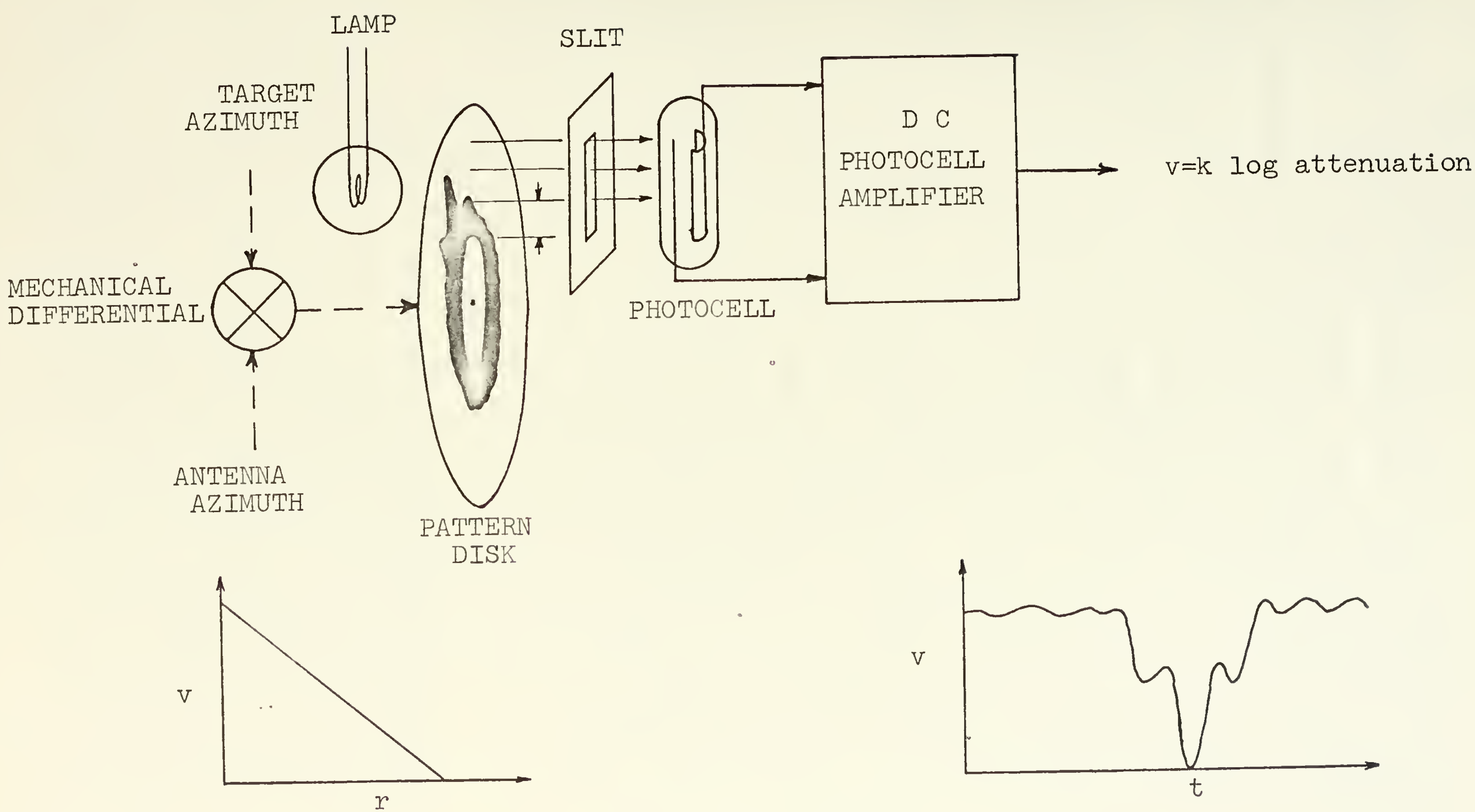


FIGURE 1. ANTENNA PATTERN GENERATOR

6. Converters

The purpose of each converter group is to act as an interface between its associated radar and the simulator console. All target pulses, chaff, and pulse jamming signals are generated at a 30 MHz intermediate frequency, and multi-jamming is generated at 5-6 GHz. The converter translates the 30 MHz IF to the radar frequency by heterodyning it with a sample of the radar stabilized local oscillator (stalo) frequency and, if necessary, a translating frequency. The 5-6 GHz IF is translated to the radar frequency by heterodyning it with a local oscillator. These simulated signals at the radar carrier frequency are combined and injected into the front end of the radar. In most converters a provision is made to sample the transmitted radar RF pulses which are then mixed with the radar stalo to form lock pulses for the 30 MHz coherent oscillator (coho) in the simulator console. This provision is utilized only if the associated radar has coherent MTI and a coho lock pulse is not available directly from the radar.

7. Interconnections

Figure 2 shows the typical interconnections between the simulator console, converter, and a search radar. Four inputs from the radar are required: antenna azimuth synchro information, radar trigger, transmitted RF or coho sample, and stalo sample. The 60 Hz, 115 V antenna azimuth synchro information is used by the antenna pattern simulation circuits and resolved to provide deflection for chaff generation

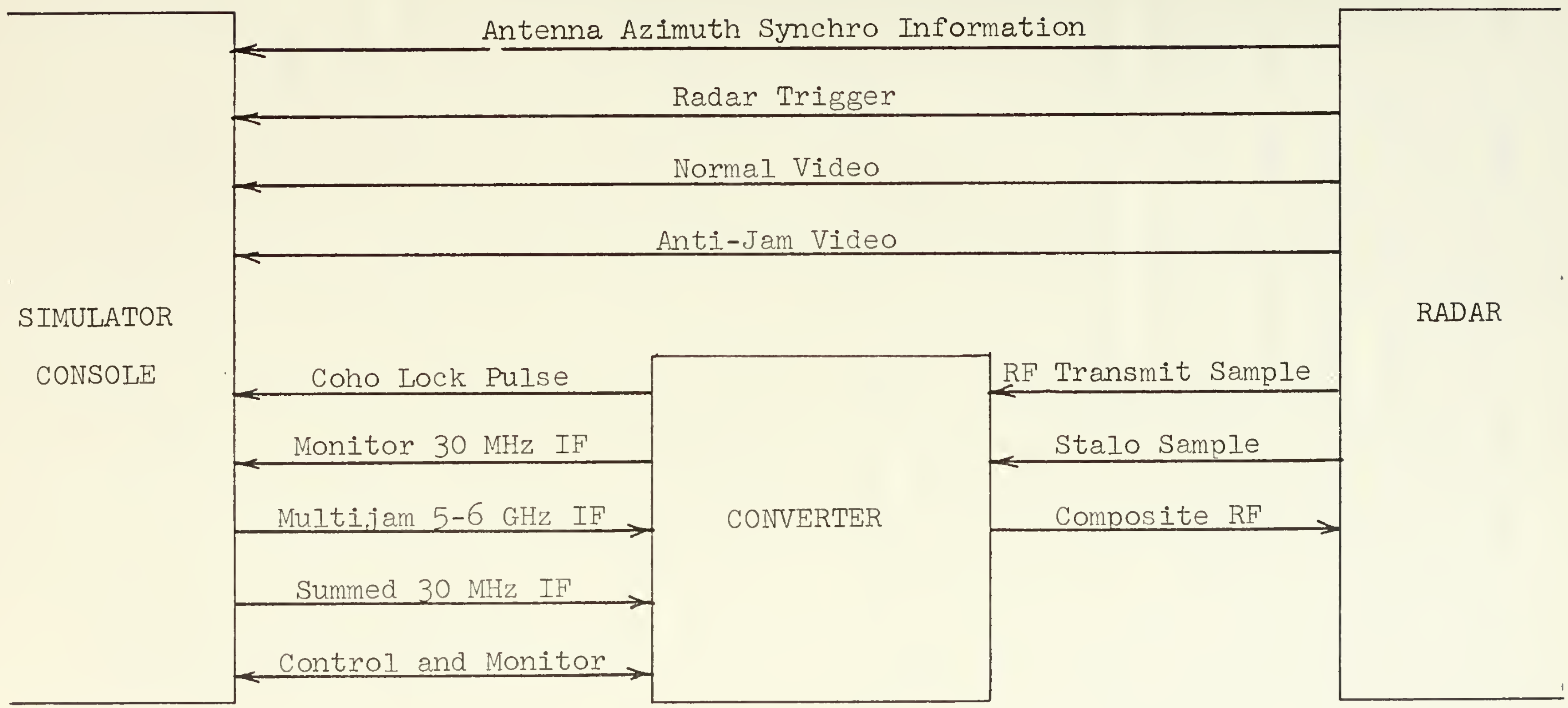


FIGURE 2. SIMULATOR AND RADAR INTERCONNECTIONS

storage tubes and PPI display on the console. The 7-100 V radar trigger is used to synchronize the simulator system with the radar. The RF transmit sample is mixed with the stalo sample in the converter to provide a coho lock pulse for the coherent 30 MHz oscillator in the simulator console. In cases where a 30 MHz coho lock pulse is available directly from the radar, the RF transmit sample is not required. In addition to providing one input for coho lock pulse generation, the stalo sample is amplified in the converter and mixed with the 30 MHz IF from the simulator console to provide simulated target, chaff, and pulse jamming at the radar carrier frequency. Provisions are also made for normal and anti-jam video inputs from the radar which can be displayed on the simulator console PPI.

In addition to power and control signals, two inputs are provided to the converter from the simulator console: summed 30 MHz IF and multijam 5-6 GHz IF. The summed 30 MHz IF is mixed with the radar stalo sample as described above. The 5-6 GHz multijam IF is mixed with a local oscillator output to provide multijamming signals at the radar carrier frequency. This multijamming RF is combined with the target, chaff, and pulse jammer RF and applied to the radar as composite RF. The monitor IF output from the converter to the simulator console is derived from the target, chaff, and pulse jammer RF developed in the converter. It is detected and can be displayed on the console PPI.

B. AN/UPS-1 RADAR

The AN/UPS-1 radar is a transportable air-search radar operating at frequencies from 1250 to 1350 MHz. The transmitter power source is a pulsed magnetron oscillator operating in one of four modes: either high or low power at either long or short pulse. The maximum rated peak output power is 1.4 MW (91.5 dBm), and minimum rated peak output power 1 MW (90 dBm) [Ref. 2] . The high and low-power modes of operation are selected manually. The long or short pulse modes depend on the maximum range selected. For a selected maximum range of 275 miles, the radar is designed to operate at a PRF of 267 pulses per second and pulse width of 4.2 μs At selected maximum ranges of 80 miles or less, it is designed to operate at a PRF of 800 with a 1.4 μs pulse width. In both cases the design duty cycle is -29.5 dB.

The receiver is a superheterodyne with a 30 MHz IF. The stalo operates 30 MHz below the radar operating frequency. Minimum discernible signal is rated as -105 dBm or better.

Coherent MTI provided in the receiver consists of amplitude limited IF and 30 MHz coho inputs to a phase detector which produces coherent video. The video is applied to a delay-line canceler which provides MTI video. The delay line is also used to generate a recirculating trigger at the PRF of 800. MTI is limited by the 1250 μs delay line to maximum ranges under 80 miles (PRF of 800). A free-running trigger oscillator generates triggers at a PRF of 267 for the maximum range of 275 miles.

The radar antenna has a modified parabolic reflector with a horizontal aperture of 16 feet and a vertical aperture of 4 feet, 9 inches. The antenna produces a horizontally-polarized wave and has a vertical beam width of 10 degrees and horizontal beam width of 3.8 degrees. Maximum gain is rated as greater than 27 dB over an isotropic radiator with maximum vertical and horizontal side lobe radiation 26 dB down.

The actual average power of the radar in the four modes of operation was measured as between 58.1 dBm and 59.5 dBm. The duty cycle was measured as -30.2 dB for short pulse operation and -29.6 dB for long pulse operation. The best MDS was measured as -113 dBm at 1310 MHz. The radar parameters assumed for all simulator power level calculations were: average transmitted power of 60 dBm, duty cycle of -30 dBm, peak transmitted power of 90 dBm, maximum antenna gain of 27 dB, and MDS of -113 dBm.

III. INTERFACING THE SIMULATOR AND AN/UPS-1 RADAR

The first task undertaken was to connect the simulator to the AN/UPS-1 MTI air-search radar. The radar operating frequency of 1250-1350 MHz and IF of 30 MHz were compatible with the OU-13/GPA-98A converter. All inputs required by the simulator were available either directly or with minor modifications to the radar.

The simulator console has provisions for inputs from three radars and the associated converters. The Radar I position is designed for an air-search radar and has provisions for coho lock-pulse input. The Radar II and Radar III positions are designed for height-finding radars and have no coho lock-pulse inputs. Since both radars to be connected were search radars, it was decided that the Radar II inputs would be modified for operation with the AN/UPS-1 radar, leaving the Radar I inputs for the AN/SPS-40A.

A. RADAR SIGNAL SOURCES

Inputs required by the simulator from the radar consist of a radar trigger, stalo sample, coho sample, antenna azimuth synchro information, and radar video. The radar trigger is required to be in the range from 7 to 100 V, and a 20 V trigger is available at radar terminal J-1802. Radar video was available at radar terminal J-807. Antenna azimuth synchro information of 115 V, 60 Hz was available at the junction box for the AN/SPA-4 repeater used in conjunction with the radar.

Modifications had to be made to the AN/UPS-1 radar in order to obtain radar stalo and coho samples. A radar stalo sample at a 11.1 dBm level was taken at the input of the radar AFC mixer using a coaxial tee-connector (Figure 3). The AFC coupling was increased to restore AFC mixer current to its normal value. A radar coho sample at a level of -16 dBm was obtained by inserting a coaxial tee-connector and DC isolating capacitor in the coho lock pulse circuits of the radar (Figure 4). Radar MTI operation was not noticeably affected.

Output from the simulator to the radar consists of simulated targets and ECM emissions at the 1.25 to 1.35 GHz radar carrier frequency. This composite RF was applied to the radar through a 37 dB directional coupler installed in the radar waveguide between the antenna, or dummy load, and the duplexer.

B. ANTENNA PATTERN SIMULATION

Additional inputs required by the simulator are horizontal and vertical antenna radiation patterns of the radar in the form of opaque patterns on transparent plastic disks. Four disks are required per radar, a vertical pattern disk and a horizontal pattern disk for each of the two simulated-target generators.

The horizontal radiation pattern of the AN/UPS-1 radar was measured and a vertical radiation pattern was determined using a "typical" pattern given in the AN/UPS-1 technical manual [Ref. 2] . A calibration curve (Figure 5) was made

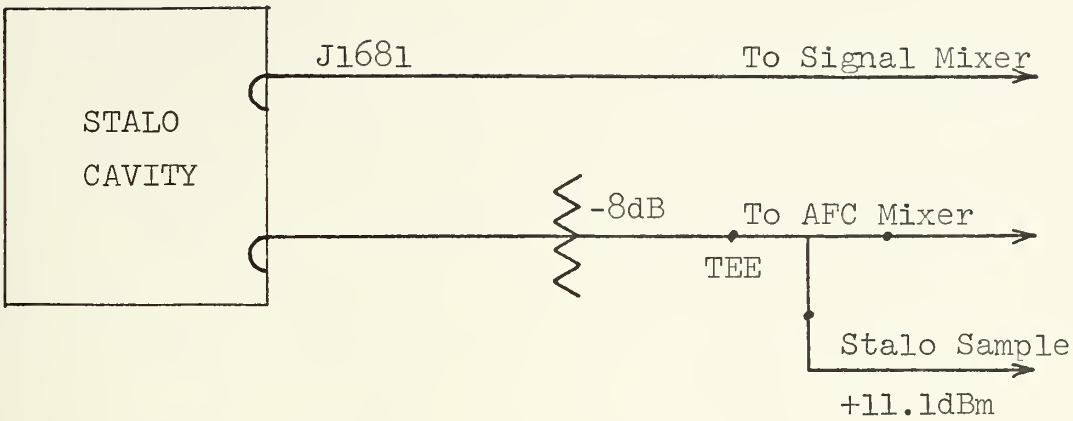


FIGURE 3. STALO SAMPLE

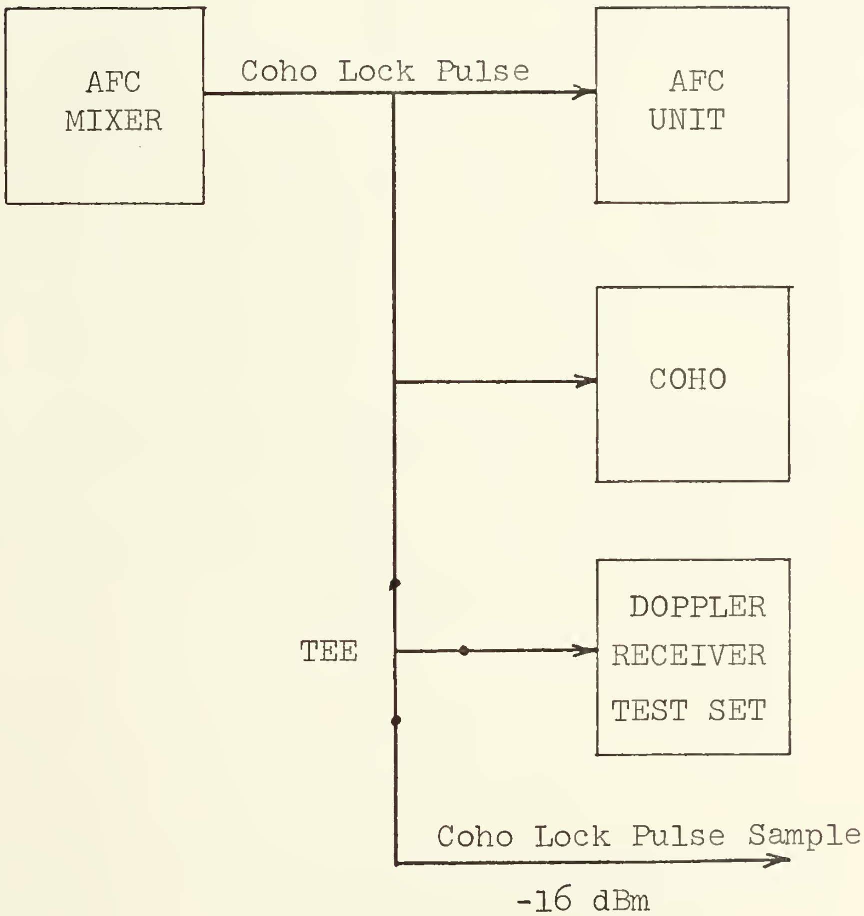


FIGURE 4. COHO LOCK PULSE SAMPLE

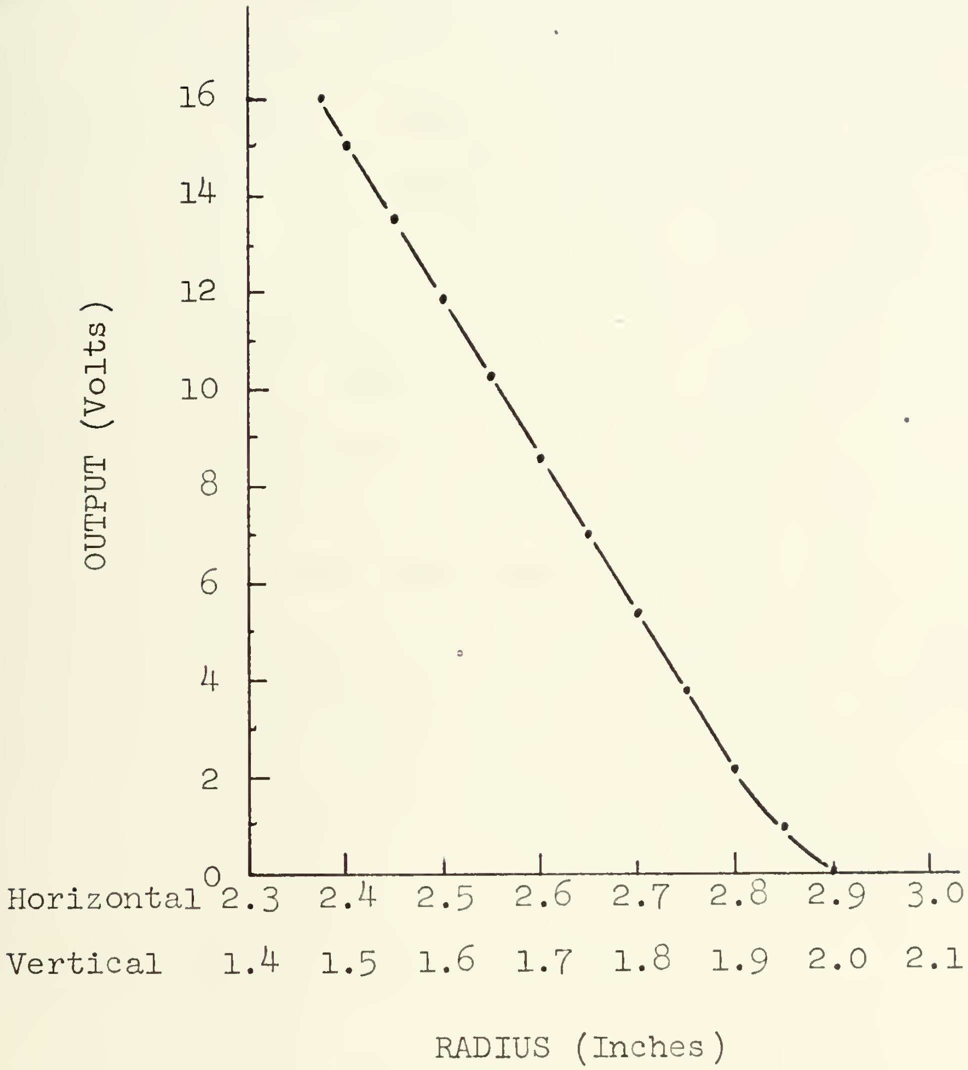


FIGURE 5. ANTENNA PATTERN SIMULATOR OUTPUT

by measuring the outputs of the pattern simulators as a function of the radius of the opaque pattern. The vertical and horizontal patterns were plotted to the scale required by the pattern simulators (Figure 6). The scaled patterns were then cut out of black opaque vinyl and glued to the transparent disks. Figures 7 and 8 show the outputs of the simulator resulting from the fabricated patterns. Although the method of producing the antenna pattern disks was quite crude, the resulting patterns provide satisfactory simulations.

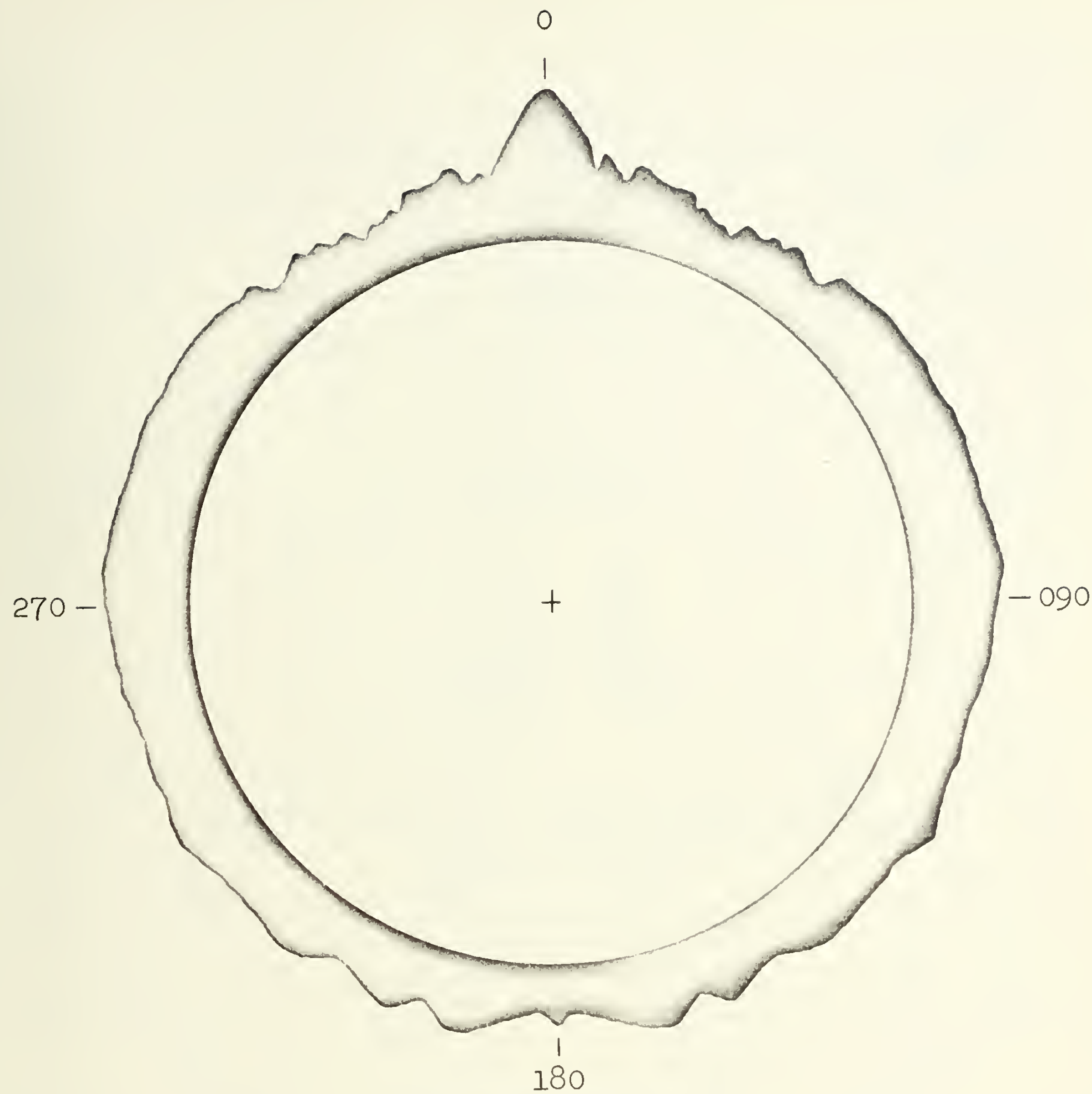
The AN/UPS-1 antenna horizontal radiation pattern was determined by measuring the power received by the antenna from a fixed CW signal source. The source consisted of an Airborne Instruments Laboratory type 124C power oscillator driving a horizontal quarter-wave dipole with a plane reflector. The frequency used was 1.3 GHz. The power delivered to the antenna was 42.6 dBm (18.2 W).

The source was placed on a tower approximately 1500 feet from the radar antenna. This distance exceeds the minimum required distance for far-field given by

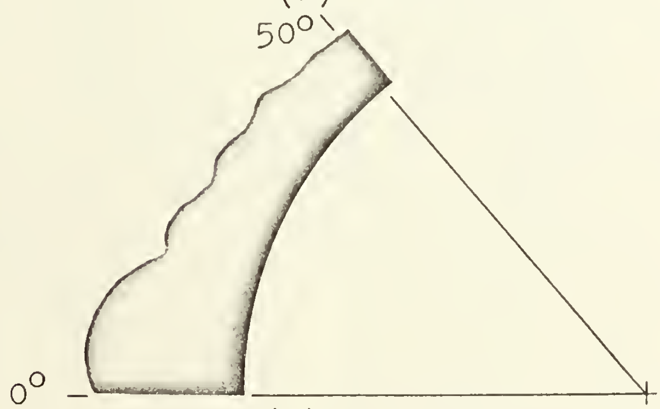
$$R = 2L^2/\lambda = 695 \text{ ft}$$

where L is the size of the aperture and λ is the wave-length. In this case L was taken as the width of the radar antenna (16.2 ft.) and λ was 0.23 meters (.755 ft.).

The equipment used to measure the received power is shown in Figure 9. The received signal was taken from the antenna waveguide through a waveguide-to-coaxial adapter and



(a) HORIZONTAL



(b) VERTICAL

FIGURE 6. SIMULATOR PATTERN DISKS

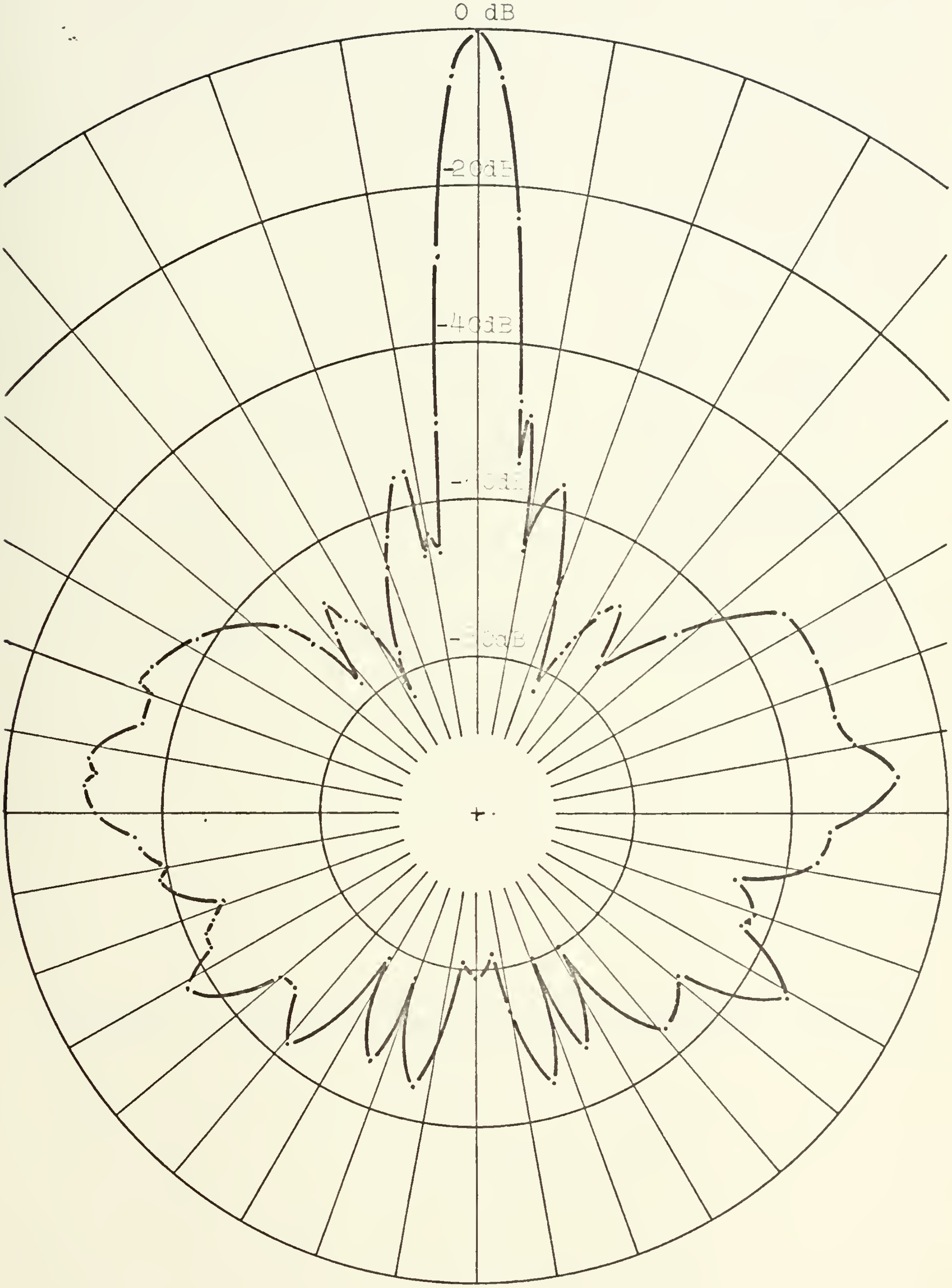


FIGURE 7. SIMULATED HORIZONTAL TWO WAY ANTENNA PATTERN

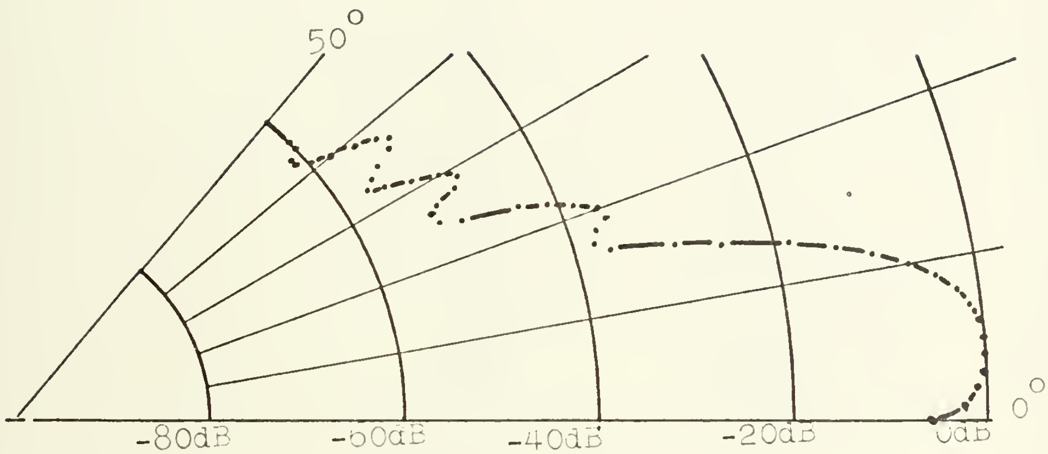


FIGURE 8. SIMULATED VERTICAL TWO WAY ANTENNA PATTERN

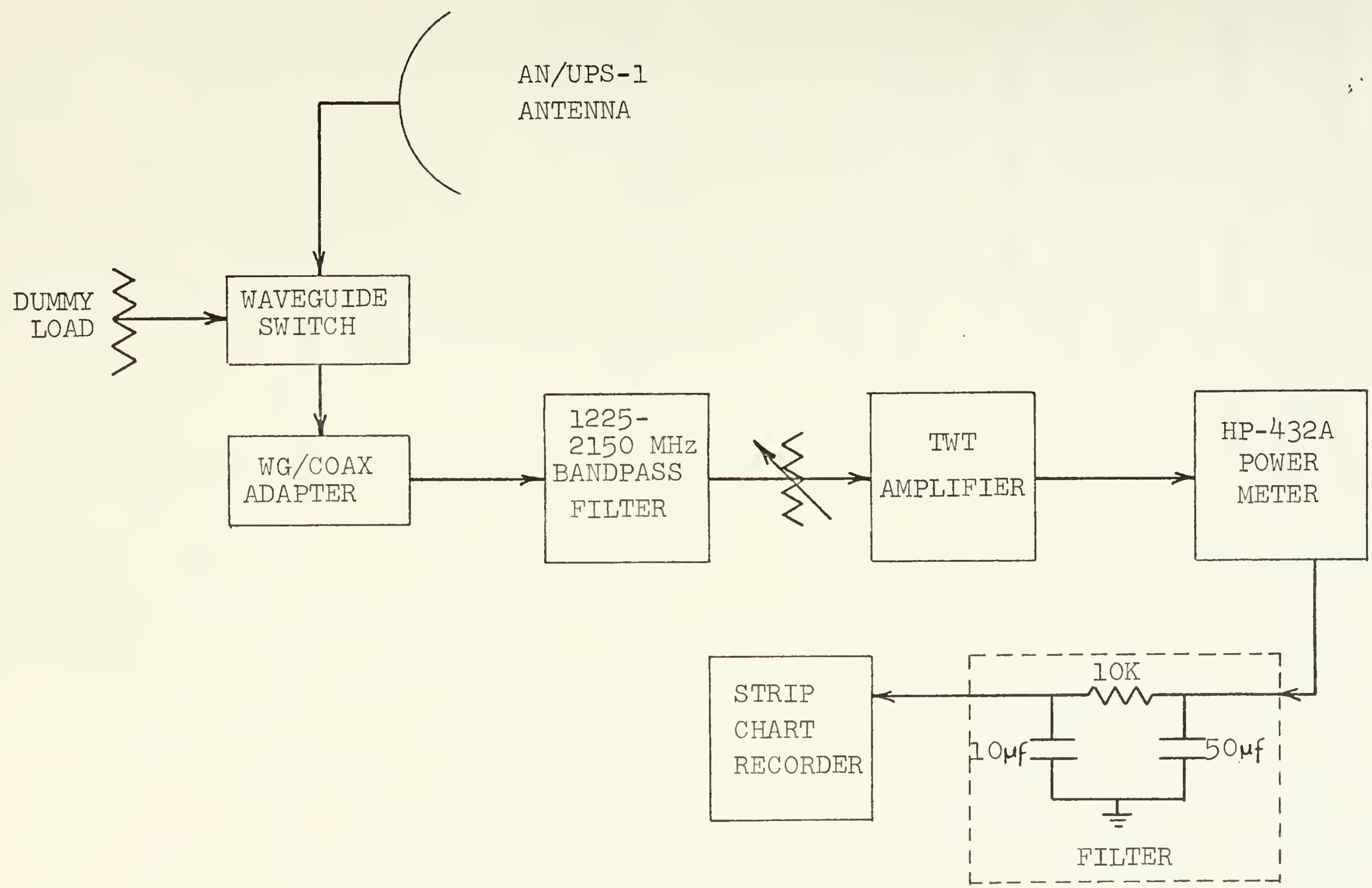


FIGURE 9. AN/UPS-1 ANTENNA HORIZONTAL PATTERN MEASUREMENT

passed through a 1225-2150 MHz bandpass filter to discriminate against undesired signals. With this arrangement no extraneous signals were observed at any antenna bearing and the noise was constant with the waveguide switched to either the antenna or a dummy load.

The TWT amplifier was necessary to bring the output power within the range of the power meter, especially when measuring the low-level sidelobe power. Various fixed attenuators were inserted in order to keep the signal level of interest, such as the main lobe and major sidelobes, within the operating region of the TWT amplifier. The output of the power meter was filtered to eliminate 60 Hz noise which was present when the two most sensitive ranges of the meter were used.

The radar antenna was rotated at a constant speed and four recordings were made of the power level during complete revolutions of the antenna. Ten degree markers were manually placed on the recording by observing the bearing indicated on the radar PPI. Each recording was made with different attenuation inserted and different sensitivity of the power meter in order to observe all ranges of the input power. The minimum discernible signal was approximately -48 dBm, which was 3 dB below the minimum signal measured in the pattern. The power level was observed with the antenna at a fixed bearing for approximately five minutes and was found to vary approximately 1.5 dB. The maximum amplitude of the main lobe was measured at the beginning and at the end of the measurements and agreed within one dB.

The power measured at the input of the bandpass filter was calibrated for each combination of attenuators and power meter sensitivity used. The source for calibration was a Hewlett-Packard model 8614 signal generator whose variable attenuator agreed within 0.5 dB when compared directly with the power meter.

The recorded relative-power pattern was tabulated and plotted on polar coordinates (Figure 10). The tabulation was accomplished by dividing the ten degree markers into ten subdivisions and recording the relative power at each degree marker using the calibrated scales. Although the antenna speed, and thus the degree scale, was found to vary somewhat, adjacent ten degree sectors compared within one degree.

Initially, pattern measurement was attempted with the signal source located at a different bearing at a range of approximately two miles. Because of the minimum discernible signal limitation of the measuring equipment, the signal power available was not sufficient to adequately measure the sidelobe pattern at that range. However, the lobes observed in the sector from 250 to 350 degrees on Figure 10 were observed at the same true bearing on the initial measurements. This confirmed that these lobes were caused by reflections from antennas adjacent to the AN/UPS-1 antenna.

Because of the reflections observed, only the portion of the measured pattern from 350 through 0 to 180 degrees was used to make the simulated pattern. Since in this sector

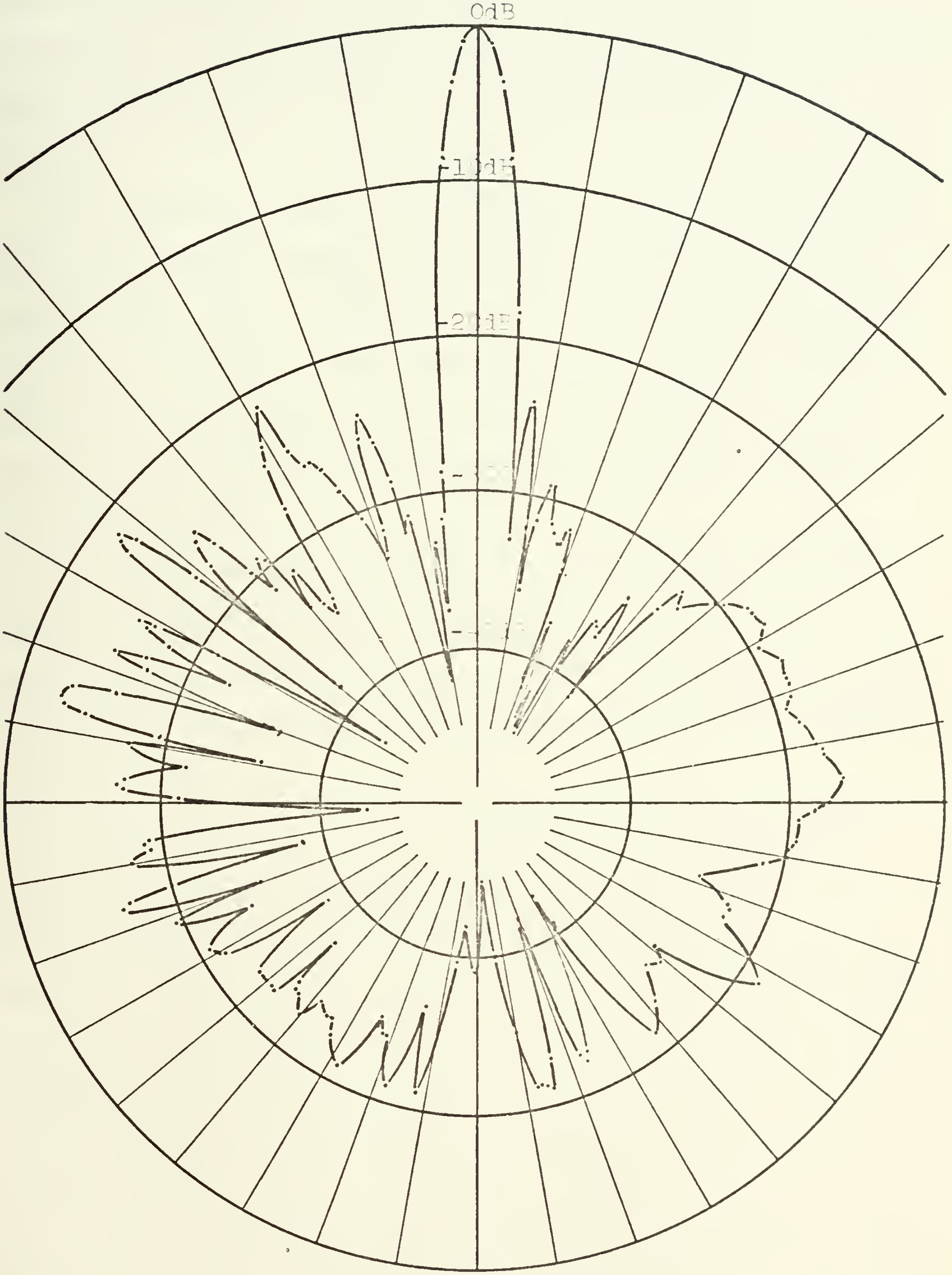


FIGURE 10. AN/UPS-1 HORIZONTAL RADIATION PATTERN

the antenna was directed away from the reflectors, it was assumed that the effect of the reflectors was negligible. The simulated pattern from 180 to 350 degrees was made equal to the measured pattern from 180 to 010 degrees.

The simulated vertical radiation pattern was determined from the "typical" pattern given in the AN/UPS-1 technical manual [Ref. 2] . Figure 11 is a polar plot of the given pattern. In order to develop some insight into the antenna pattern, an investigation was made of the pattern which results from placing the antenna over a plane, perfectly reflecting earth.

The radar antenna is tilted at a five-degree elevation angle. An antenna height, h_a, of 75 feet was assumed, approximating the actual antenna height above ground level. A sketch of the geometry of the problem is given in Figure 12(a).

For a perfectly reflecting earth, the electric field at point P can be determined from the phasor sum of the direct field and the field from the mirror image of the antenna. The magnitude of the resultant field is dependent upon both the magnitude and phase of the two fields. The angles θ and ϕ can be assumed to be equal when the distance, R, is very much greater than the antenna separation, $2h_a$. The field at point P is then the resultant of two fields at $(\theta - 5)$ degrees and $-(\theta + 5)$ degrees with respect to the pattern axis. Figure 13 shows the direct field (curve (a))

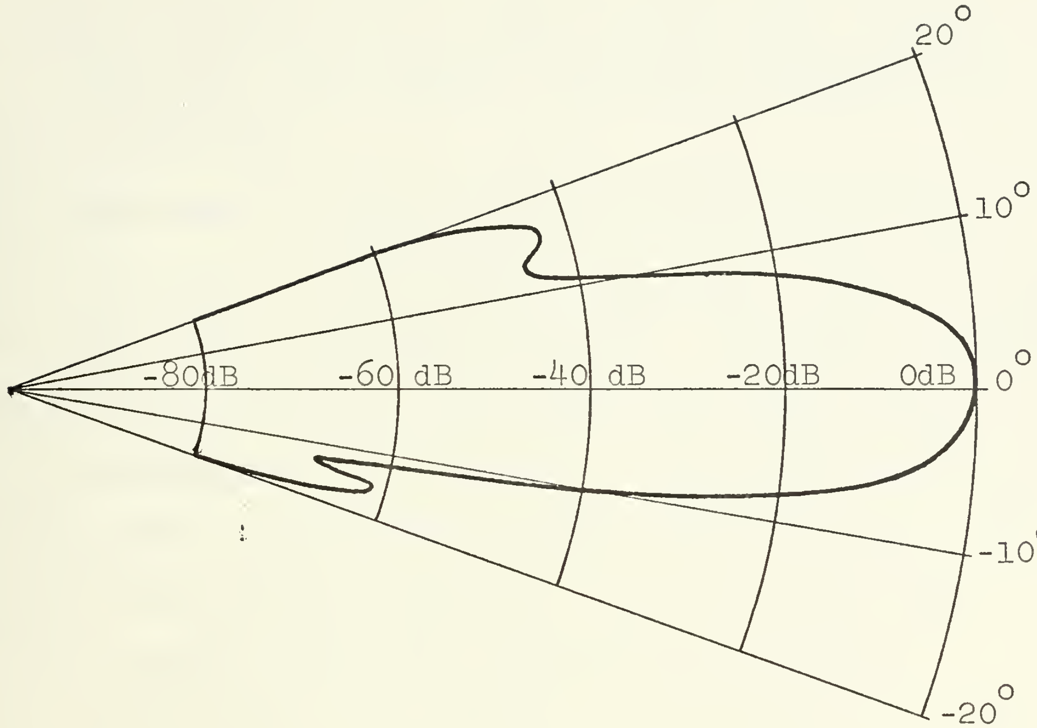


FIGURE 11. AN/UPS-1 VERTICAL RESPONSE PATTERN

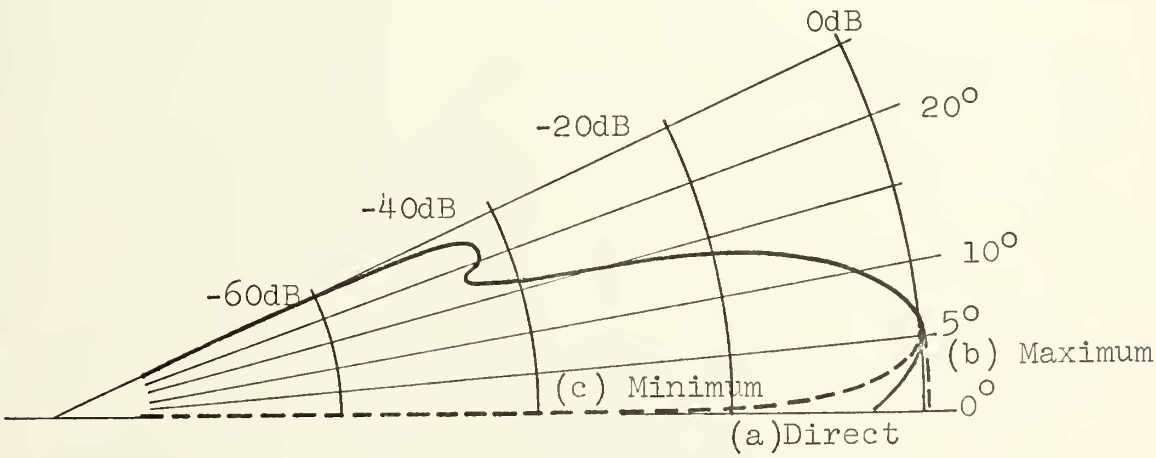


FIGURE 13. VERTICAL RESPONSE WITH PLANE REFLECTING SURFACE AND FIVE DEGREE ANTENNA TILT

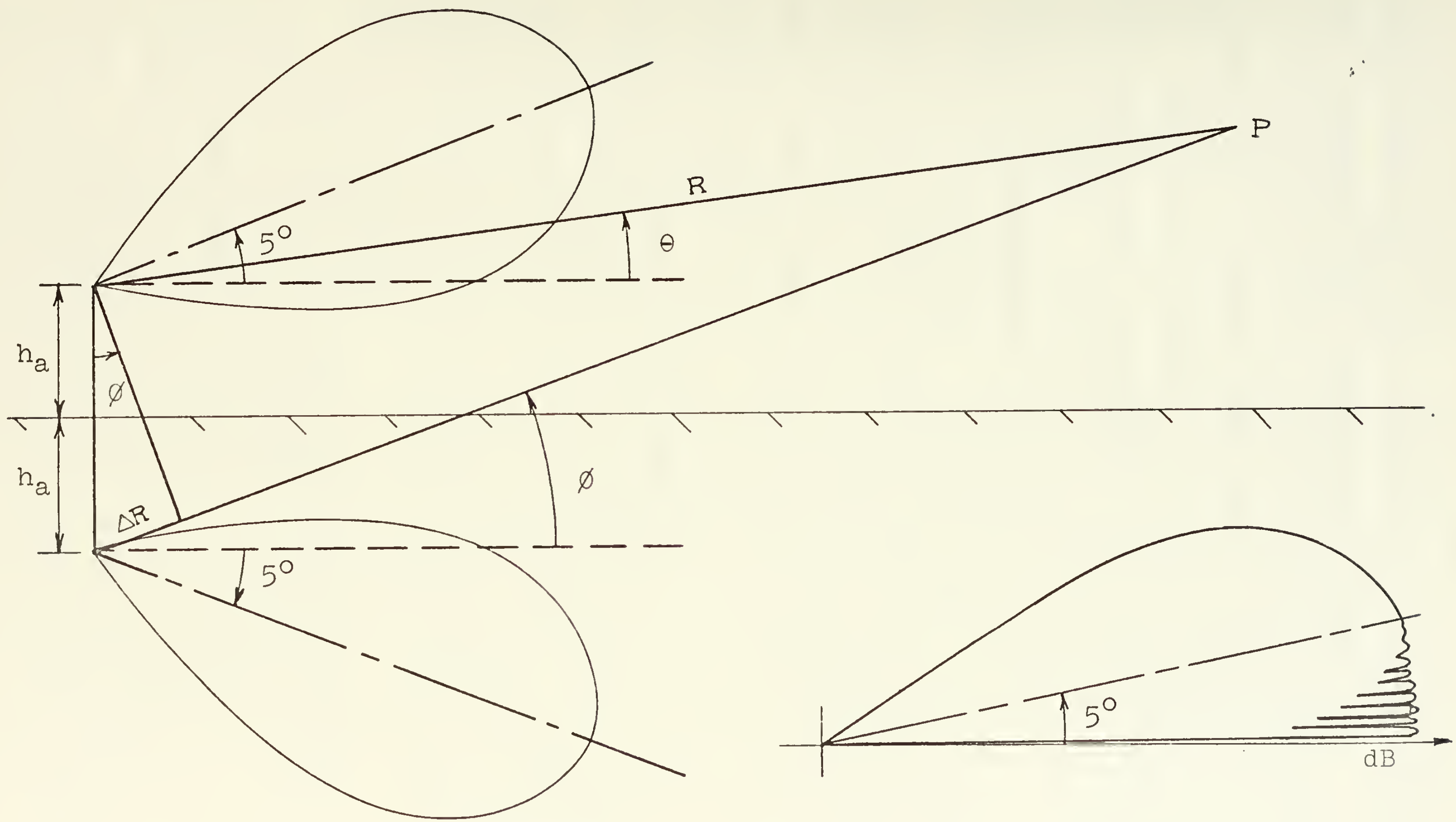
and the resultants of the direct and reflected field in phase (curve (b)) and out of phase (curve (c)). Curves (b) and (c) constitute the envelope for field variations due to phase differences.

The difference in path length of the direct and reflected waves, ΔR, is given by $\Delta R = 2h_a \sin\phi$. Since $R \gg 2h_a$, angles ϕ and θ are approximately equal. The path difference is given by $\Delta R = 2h_a \sin\theta$. The phase shift, Ψ_d, due to the path difference is $\Psi_d = 2\pi\Delta R/\lambda = 4\pi h_a \sin\theta/\lambda$ where λ is the wavelength. Since perfect reflection was assumed, the reflected wave is also shifted by π and the total phase difference between the direct and reflected waves is $\Psi = \Psi_d + \pi = 4\pi h_a \sin\theta/\lambda + \pi$. Minima occur whenever the two waves are out of phase. Therefore, the phase difference is give by $\Psi = (2n+1)\pi = 4\pi h_a \sin\theta/\lambda + \pi$ where n=0, 1, 2, 3..., and the elevation angle by $\theta = \sin^{-1}\dfrac{n\lambda}{2h_a}$. Similarly, maxima occur whenever

$$\Psi = 2n\pi = 4\pi h_a \sin\theta/\lambda + \pi, \quad n=1,2,3\ldots, \text{ and } \theta = \sin^{-1}(2n-1)\frac{\lambda}{4h_a}.$$

The number of maxima that occur between 0 degrees and 5 degrees can be determined by solving for n at 5 degrees. Given that $h_a = 75$ ft $\simeq 23$m and $\lambda = 0.23$m, then $\theta = 5\text{deg} = \sin^{-1}\dfrac{2n-1}{400}$ and $n \simeq 18$. The antenna pattern for a perfectly reflecting, flat earth would consist of the pattern due to the direct ray modified by approximately eighteen maxima and minima as sketched in Figure 12(b).

The loci of maxima and minima shown for perfectly reflecting earth are the maximum variations that can occur. Any deviation from perfect reflection would cause the



(a) Antenna and Image

(b) Resultant Pattern

FIGURE 12. VERTICAL RESPONSE PATTERN FOR A PLANE PERFECTLY REFLECTING SURFACE

variation to decrease. The positions of the maxima and minima would also shift slightly but the rate of variation with elevation angle would remain the same.

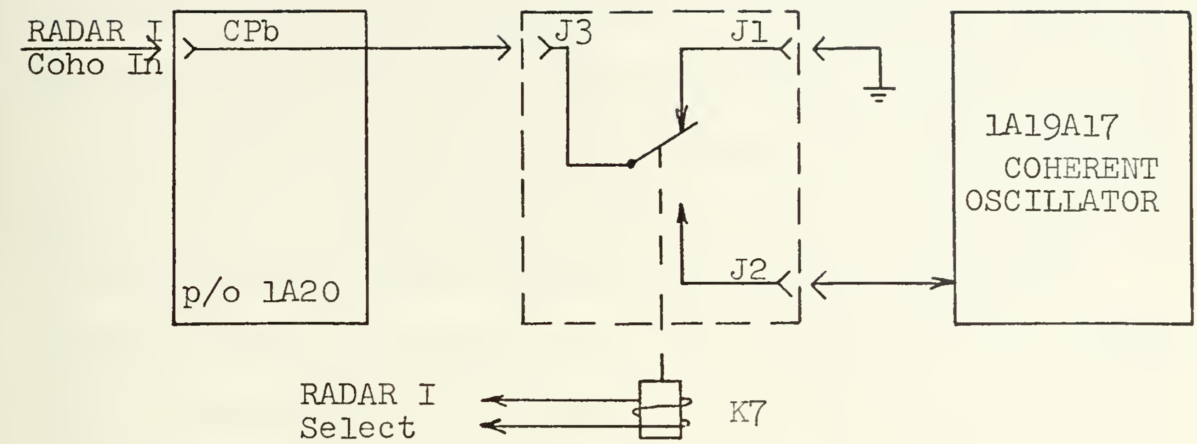
The pattern chosen to simulate the vertical antenna pattern was the direct field pattern, curve (a) of Figure 13. The terrain in which the radar is located is broken by many trees, hills and buildings, and can be considered a poor reflector. Therefore, the simulated pattern should be a close approximation of the direct pattern.

If a lower antenna elevation angle had been used, the direct field pattern would not have been as good an approximation. At very low angles an average between the direct field pattern and the locus of maxima would probably be more appropriate.

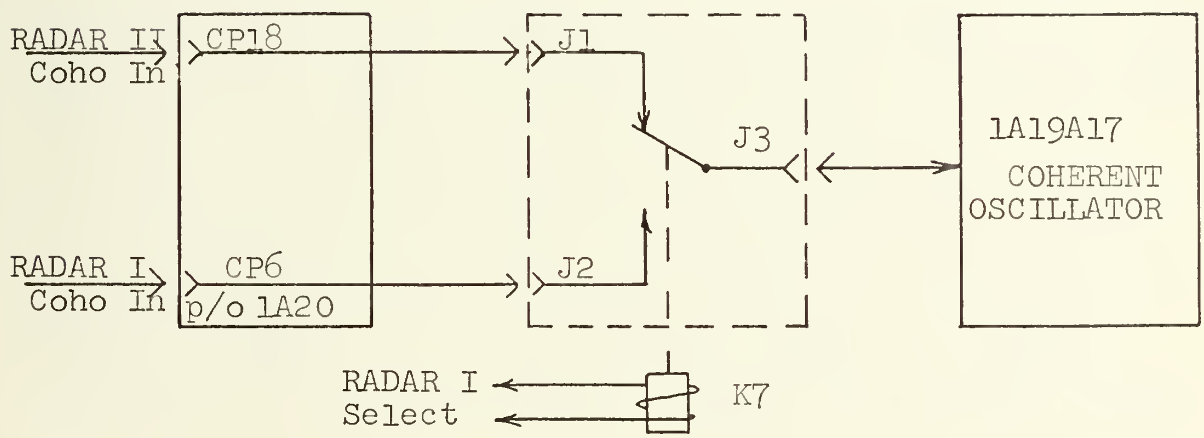
C. MODIFICATIONS TO THE SIMULATOR

As previously noted, the Radar II inputs to the simulator were designed for height-finding radars. In order to adapt the console for search radar inputs, a provision had to be made for coho lock-pulse input and internal signal routing had to be modified.

Coho lock-pulse input was accomplished using a spare connector, CP 18, on the Radar II section of the power and signal distribution panel, unit 1A20 [Ref. 1]. In the original circuit (Figure 14(a)) coho lock-pulses from the Radar I position were applied to the coho whenever coaxial relay K7 was energized by the Radar I select switch. When either Radar II or III was selected, relay K7 was deenergized, the Radar I coho lock pulse grounded, and lock-pulse input



(a) Original Circuit



(b) Modified Circuit

FIGURE 14. COHO LOCK PULSE MODIFICATION

to the coho open circuited. As modified (Figure 14(b)) the relay applies lock pulses from the Radar I input when Radar I is selected (relay K7 deenergized). No effect was noted on the operation of the radar with the relay in either position.

Five relays normally select antenna azimuth or elevation information depending upon whether a search radar (Radar I) or height-finding radar (Radar II or III) is selected. Antenna azimuth information is selected whenever the relays are not energized by the Radar I select switch. Since only search radars were to be connected, the relay coils were disabled so that azimuth information would always be selected. The disabled relays were: 1A17A20-K1 and 1A17A22-K1 which select either azimuth or elevation resolvers for x-y sweep resolvers; 1A17A25-K1 and K2 which select either azimuth or elevation patterns for the chaff input programmer; and 1A17A7-K1 which selects either an azimuth north-pulse or a clock pulse generator as the clock for the chaff programmer.

A 10 kilohm potentiometer designated 1A1-R2A was added to provide a DC antenna elevation signal for the Radar II position (Figure 15). The elevation signal is normally provided as a sine of elevation signal from a height-finding radar.

Two additional modifications were found to be necessary while aligning the simulator console. The 1 kilohm resistor 1A17A13 was replaced by a 470 ohm resistor to increase the resolver drive to the required level. The 10 kilohm

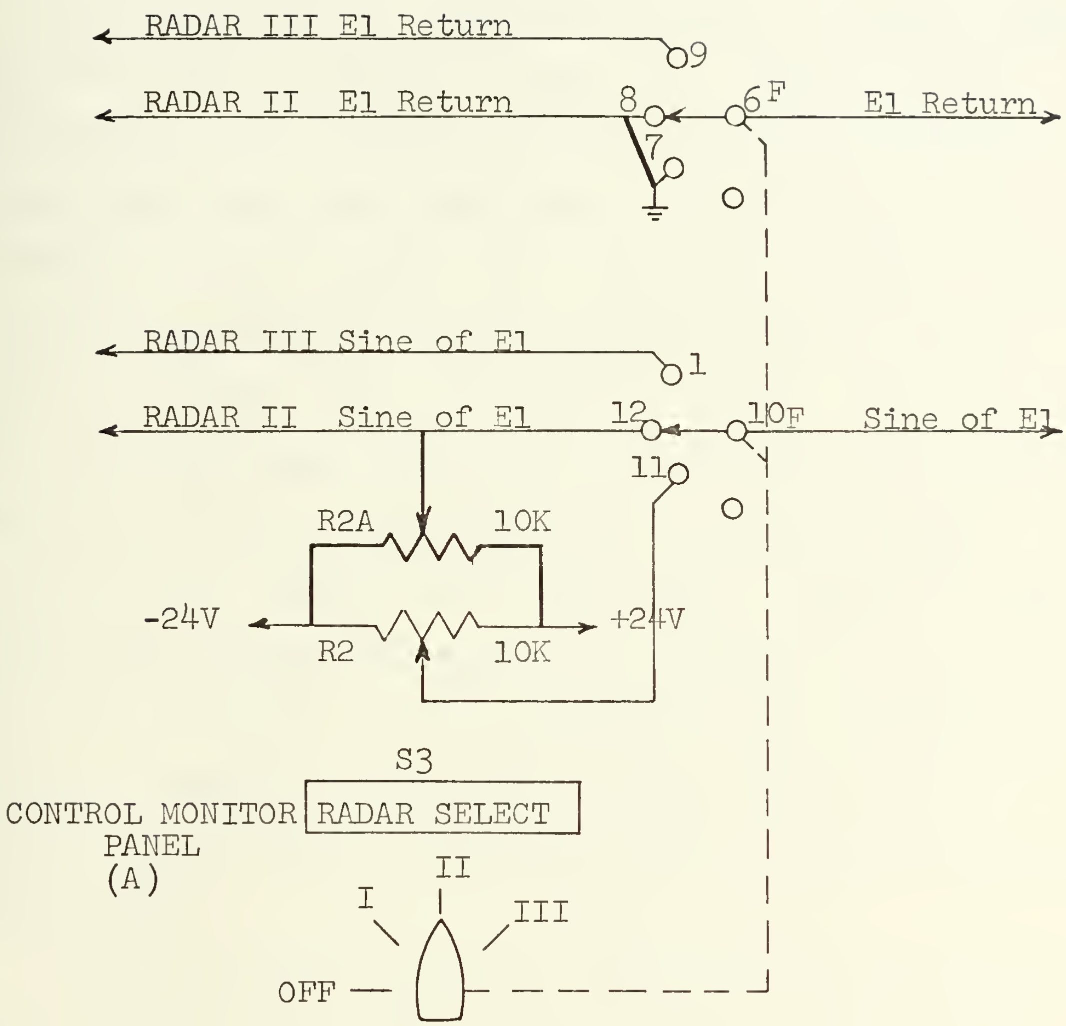


FIGURE 15. RADAR II ELEVATION MODIFICATION

resistors to increase the sensitivity of the sweep failure interlock amplifiers and prevent erroneous sweep failure interlock operation.

D. INTERCONNECTIONS

Interconnections between the simulator console, converter, and the radar are shown in Figure 16. Antenna synchro information and simulator console-to-converter control signal connections were made using type 1404 and 6100-7 multi-conductor cables (Figure 17). Fifty-ohm impedance coaxial cable was specified by the AN/GPA-98A technical manual [Ref. 1] for all video, IF, and RF signals. Since all cable runs were less than thirty feet, RG-58C/U coaxial cable was used for all connections except the 5-6 GHz multijam IF and 1.25-1.35 GHz composite RF to the radar. Typical RG-58C/U losses were measured as 0.5 dB at 30 MHz and 1.1 dB at 1270 MHz. Six feet of RG-9/U (0.7 dB attenuation at 1300 MHz) was used for the composite RF and approximately thirty feet of FHJZ-50 Heliax (1.3 dB attenuation at 5-6 GHz) was used for multijam IF.

After all interconnections between the simulator and AN/UPS-1 radar were made, the simulator was aligned using the procedure given in the AN/GPA-98A technical manual [Ref. 1] . Attenuators were then added to the IF and RF lines to adjust the signal levels for proper operation.

The output power of the stalo amplifier of the OU-13/GPA-98 converter (Figure 18) is specified by the technical manual [Ref. 1] as +8 dBm with the TWT amplifier operating in the

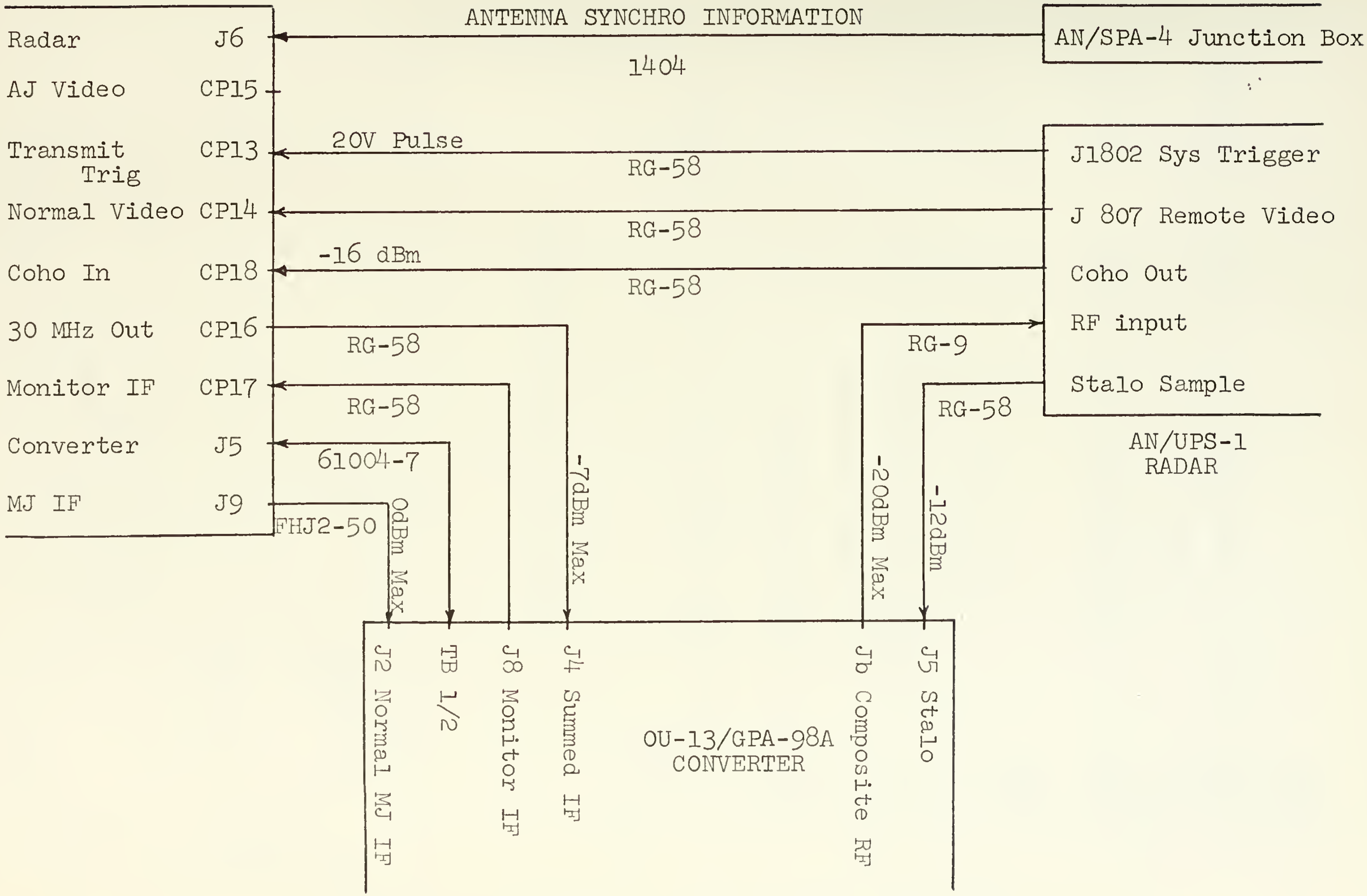
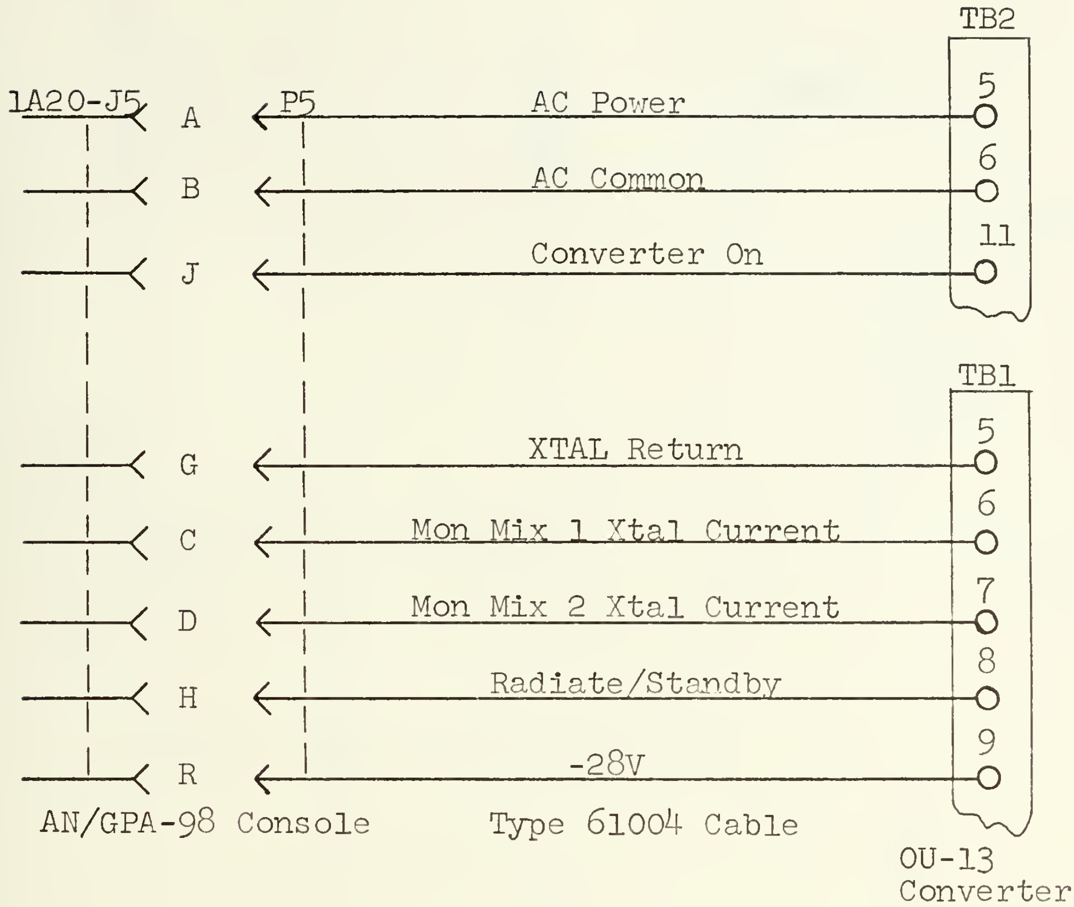
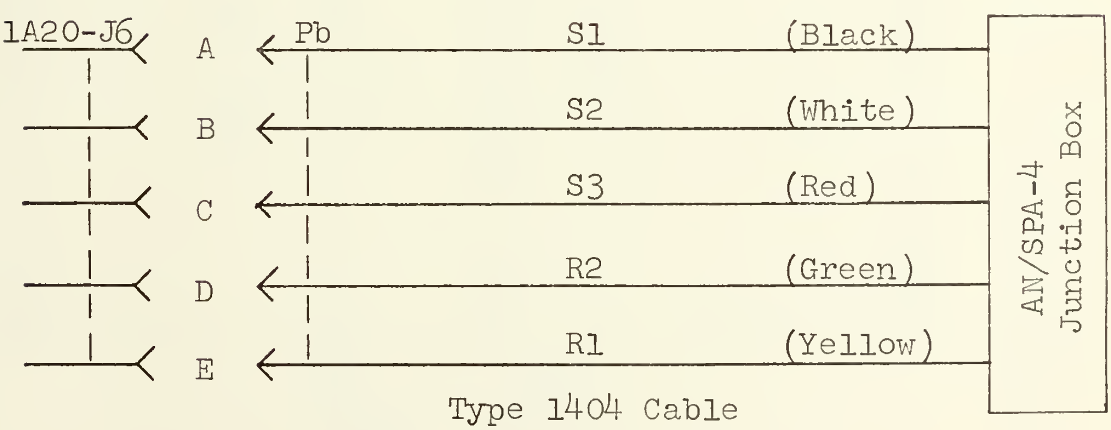


FIGURE 16. SIMULATOR TO RADAR INTERCONNECTIONS



CONVERTER CONTROL AND MONITOR



ANTENNA SYNCHRO INFORMATION

FIGURE 17. MULTICONDUCTOR CABLE CONNECTIONS

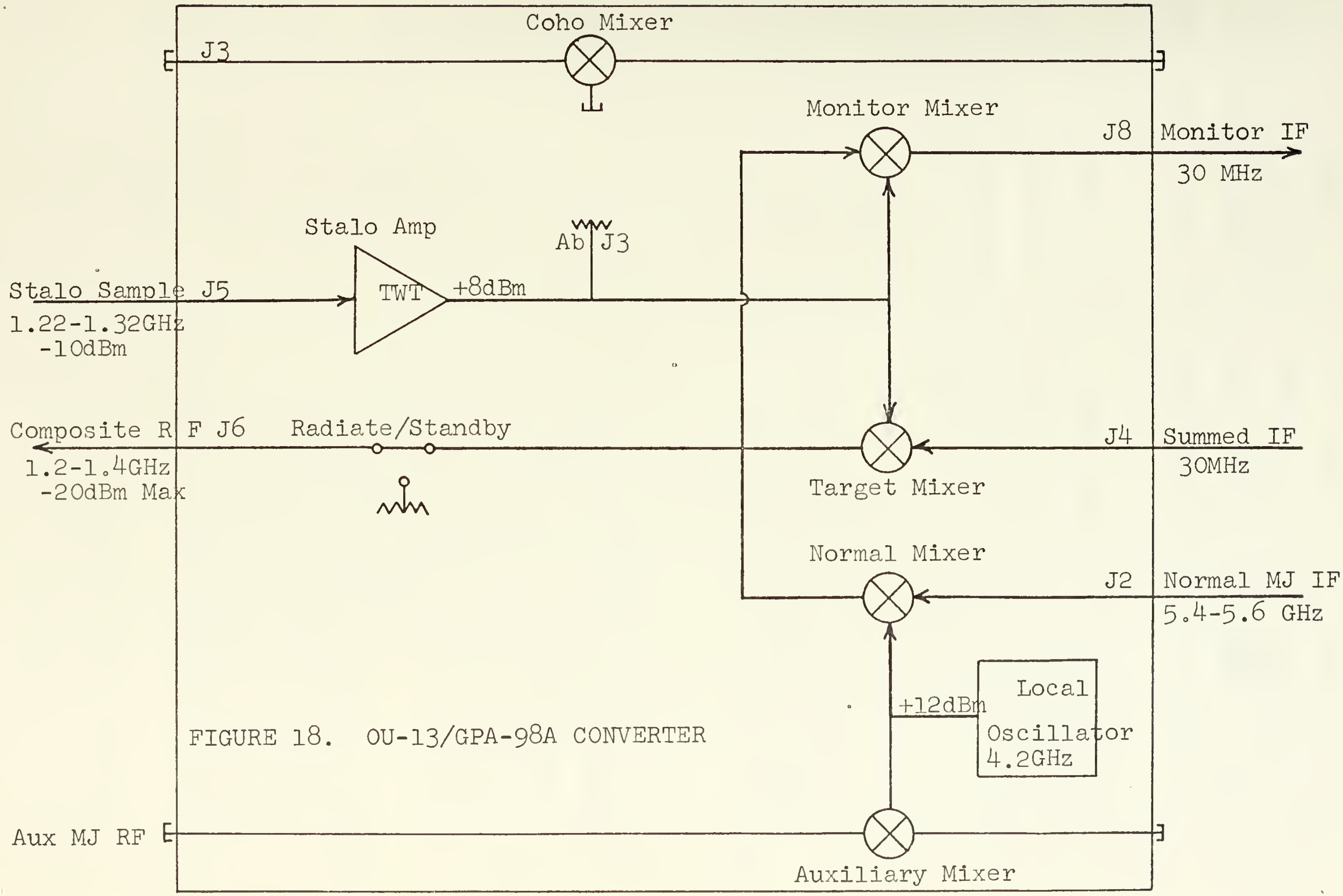


FIGURE 18. OU-13/GPA-98A CONVERTER

saturated region. The input signal level required at the converter stalo sample connector, J5, was measured as -12 dBm. A 20 dB attenuator was placed at the stalo sample output of the radar to reduce the input power at the converter to -11.4 dBm.

The maximum output of radar carrier-frequency signal power is specified as -20 dBm at the converter composite RF output connector, J6. The input signal level required at the summed IF input connector, J4, to produce -20 dBm output was measured as -7 dBm. The maximum 30 MHz IF output power from the console was measured as +10 dBm. A 15 dB attenuator was placed at the console 30 MHz IF output connector, CP 16, to reduce the input power at the converter to -7 dBm maximum.

The maximum input power at the converter normal multijam IF input, J2, required to produce -20 dBm at the composite RF output, was measured as 0 dBm. The maximum multijam IF output was measured as 18 dB. A 16 dB attenuator was placed at the console multijam IF output connector, J9, to reduce the input power at the converter to 0 dBm.

One schematic of the AN/GPA-98A technical manual (Figure A-67 of Ref. 2) indicates that the amplitude of the coho lock pulse at the input of the first lock-pulse amplifier should be 55 mV. The amplitude of the lock pulse from the radar was measured as 35 mV.

The maximum RF output of the converter with Radiate/Standby switch (Figure 18) in the standby position is rated

as -90 dBm [Ref. 1] . Attenuation is required between the composite RF output of the converter and the front end of the radar to keep the -90 dBm at least 10 dB below the radar MDS [Ref. 1] . The AN/UPS-1 radar MDS is -113 dBm. Therefore, at least 33 dB of attenuation is required. A 37 dB directional coupler was used to couple the converter to the output of the radar. The coupler attenuation exceeds the minimum attenuation required while maintaining adequate signal levels.

E. FINAL SIGNAL LEVELS

Final signal levels were determined by calculating the power received at the radar front end due to targets and to jamming signal sources. The peak power received due to targets was calculated using a simple form of the radar equation [Ref. 3] .

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

where P_t = peak power transmitted, watts

G = radar antenna gain

λ = radar wavelength, meters

σ = radar cross-section of target, square meters

R = target range, meters

Given the parameters P_t = 90 dBm, G = 27dB, and λ = 0.231m (f=1.3GH$_3$), the above equation reduces to the form

$$P_r(\text{dBm}) = -32 \text{ dBm} - 40 \log R + 10 \log \sigma$$

where the received power, P_r, is in dBm; range, R, in miles; and target cross sections, σ, in square meters. In Figure 19 the received power is shown as a function of target range for various target radar cross sections. In particular, for a target radar cross section of 10 square meters at a range of 50 miles, the received power, P_r, is -90 dBm.

The simulator target output was calibrated by manually setting the targets to a range of 50 miles, target cross section to 10 square meters, and adjusting the simulator gain for -90 dBm input to the radar. This was accomplished by setting the target output for CW instead of pulse operation and adjusting the gain for an input of -90 dBm + 37 dB = -53 dBm at the input to the 37 dB directional coupler. A calibrated spectrum analyzer was used to observe the signal level.

The power received at the radar front end due to jamming sources was calculated using the equation

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^2 R^2}$$

where P_t = power transmitted by jammer, watts

G_t = gain of jammer transmitting antenna

G_r = gain of radar (receiving) antenna

λ = jammer wavelength, meters

R = jammer range.

Given the parameters G_t = 27 dB, G_r = 1, and λ = 0.231m

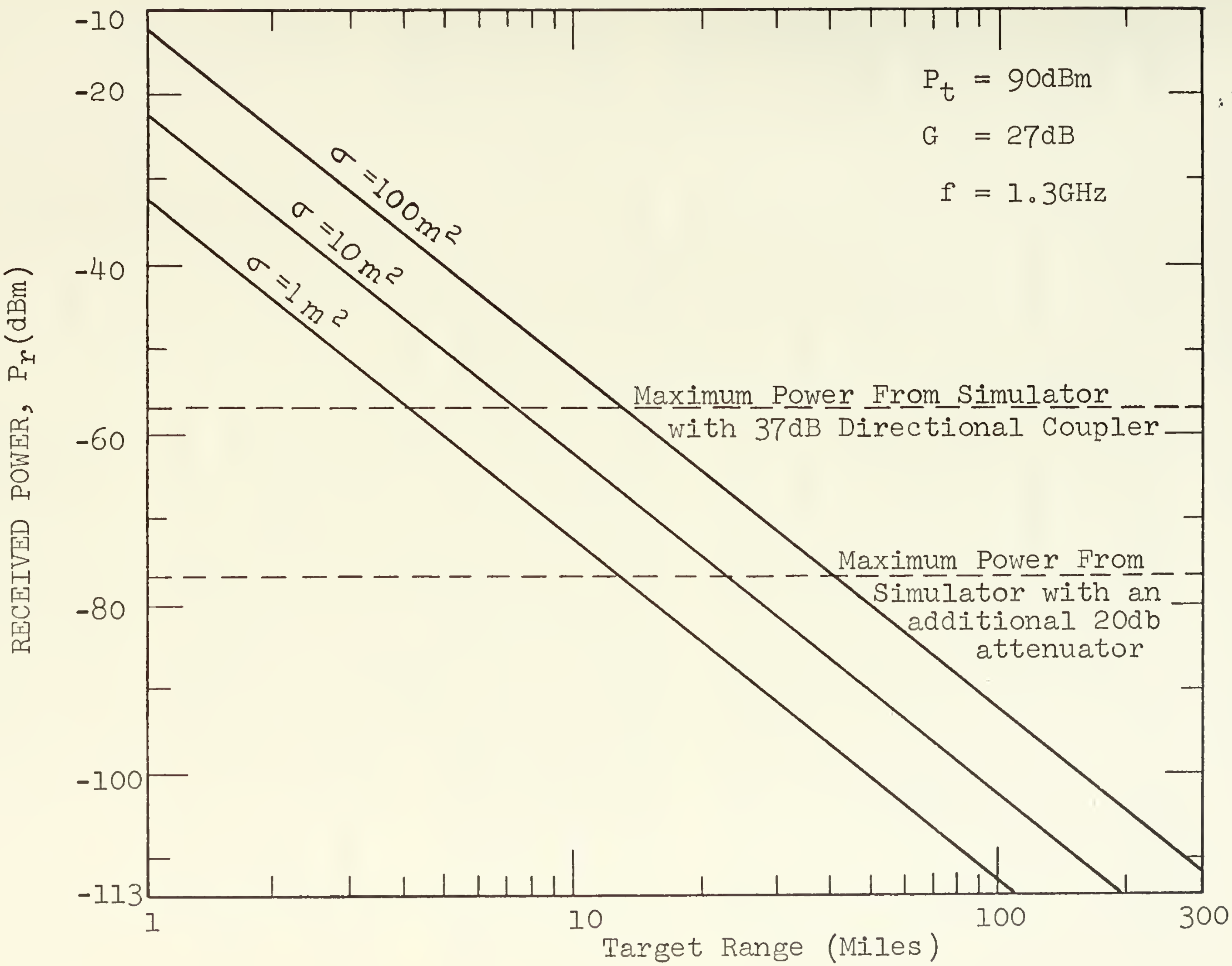


FIGURE 19. RECEIVED POWER AS A FUNCTION OF TARGET RANGE AND CROSS SECTION

the equation is reduced to the form

$$P_r(\text{dBm}) = P_t(\text{dBm}) - 73\text{dB} - 20 \log R(\text{mi})$$

Figure 20 shows the received power, P_r, as a function of range for various jammer powers and modes.

The simulated pulse-jamming output was calibrated by setting the simulated jammer at 50 miles with 500 W (57 dBm) output in the invert (-40 dB) mode. The calculated received power is then -90 dBm. The jammer output was set for CW operation and the signal level at the input to the coupler and attenuator adjusted for the same level as for the simulated target above.

The multijammer output power is given by the same equation as for the pulse jammer. For a multijammer power of 10 watts at a range of 50 miles the received power is -67 dBm. The multijammers were placed in the CW mode and adjusted for a -30 dBm input at the coupler.

Chaff power is adjusted to have the same power, with chaff density control at midrange, as a 10 m^2 target at 100 miles (-102 dBm at the radar or -65 dBm at the directional coupler). This allows maximum chaff density adjustment at both extremes of range.

When the radar is transmitting at the same time that the simulator is in the radiate mode, additional isolation is required between the directional coupler and the converter in order to protect the mixer diodes in the converter. It was found that 35 dB of additional attenuation was sufficient

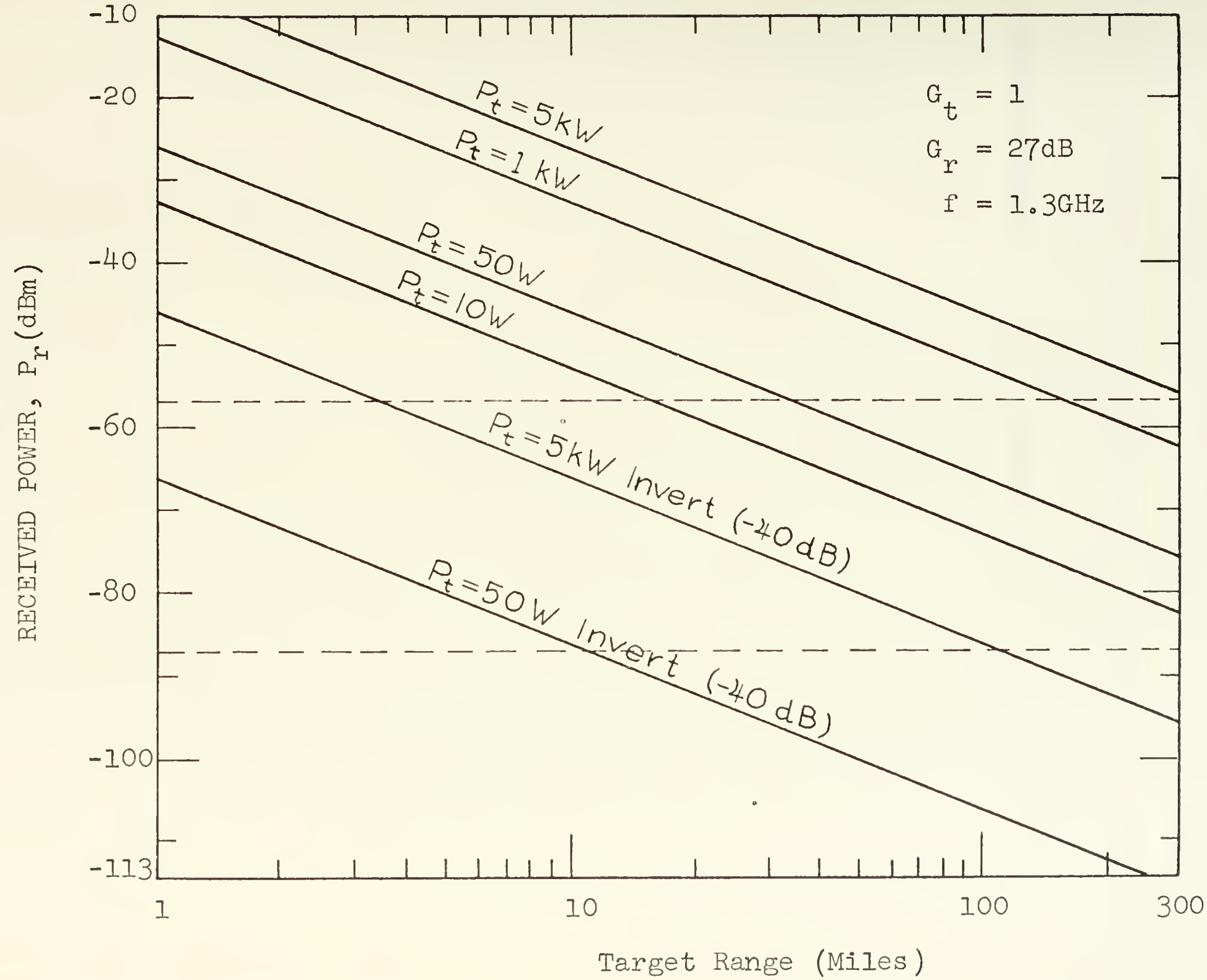


FIGURE 20. RECEIVED POWER AS A FUNCTION OF JAMMING POWER AND RANGE

to protect the diodes. However, the additional attenuation would limit the maximum input from the simulator into the radar to -92 dBm, which is inadequate for the simulation of most target and jamming signals. A directional attenuator, such as a ferrite isolator, is required in order to simultaneously use the simulator and radiate the radar.

IV. RESULTS AND CONCLUSIONS

After the initial installation of the AN/GPA-98A simulator and interconnection of the simulator console, converter, and the AN/UPS-1 radar was completed, considerable time was required to align and trouble-shoot the AN/GPA-98A simulator. Most of the difficulties encountered in its repair and alignment were due to unfamiliarity with the detailed operation of the simulator. Although solution of these problems resulted in a better understanding of its operation, it detracted from time which could have been spent determining the interfacing of the simulator with the AN/SPS-40A radar. Some of the troubles which were encountered are listed: a shorted diode in the -28 V DC power supply, insufficient drive to the x-y coordinate resolver which resulted in short sweeps on the simulator PPI and chaff storage tubes, erroneous operation of chaff storage tube sweep failure interlocks which resulted in inoperative chaff generators, low power output from one multijammer, continuous 18 MHz amplitude modulation of the output of the other multijammer, improper tracking of the antenna elevation pattern simulator, and overheating of the simulator PPI CRT high-voltage power supply. The low output multijammer and high-voltage power supply were not repaired, but the remaining circuits of the simulator were properly aligned, power levels adjusted, and the interfacing completed.

Aircraft targets with radar cross sections of from 1 to 100 square meters can be simulated at ranges from approximately 10 miles to the maximum range of the radar (Figure 19). Simulated chaff can be displayed for similar ranges. From Figure 20 it appears as if simulated pulse jamming and multi-jamming are limited to low simulated power or long ranges. This is true, however, only when the simulated emitter is located in the main lobe of the radar antenna pattern. At any other antenna bearing the simulated jammer is in the side lobes of the antenna radiation pattern and considerably less power is required at the radar front end in order to simulate the jamming. For example, assuming that the jammer is in a sidelobe whose gain is at least 26 dB below the gain of the main lobe, the minimum range for accurate simulation of 5 KW pulse jamming is at most 18 miles. Even when the jammer bearing is in the main lobe of the antenna pattern the jamming power usually exceeds the simulated target power so that the display at the radar appears quite realistic.

As noted previously, in order to simultaneously radiate the radar and operate the simulator, an additional simulator isolation of 35 dB is required. However, it is possible to radiate the AN/UPS-1 radar in the short-pulse mode (1.4 μs pulse, 80 miles maximum range) with only 20 dB additional isolation. If an attenuator, rather than a one-way isolator, is used, the gains of the simulator targets, chaff, and jammers must be increased 20 dB to compensate for the added attenuation. Since the maximum output of the simulator is

fixed at -20 dBm, simulated target cross sections and jammer powers are severely limited as indicated in Figures 19 and 20. It would be preferable to isolate the simulator with a one-way device such as a -35 dB ferrite isolator. Then the simulator could be used with maximum capabilities and at all modes of radar operation.

Only two simple adjustments are required on the simulator in order to switch between operation in the long and short-pulse modes. The target pulse width must be adjusted to match the radar pulse width, and the simulator sweep gate must be adjusted to correspond to the PRF of the radar . (See Ref. 1)

As presently installed, the AN/GPA-98A countermeasures simulator is a convenient source of a variety of countermeasures signals for use against the AN/UPS-1 radar. It provides much greater flexibility and realism than could reasonably be obtained using test equipment or constructing individual jammers. The AN/GPA-98A is the only readily available source of chaff simulation in the laboratory, and it is not practical to make actual chaff drops for demonstration purposes.

The AN/GPA-98A countermeasures simulator provides the Naval Postgraduate School radar laboratory with the capability to demonstrate the effects on the AN/UPS-1 radar of a variety of countermeasures--pulse jamming, high duty cycle AM/FM jamming, and chaff. It also provides the students with a convenient source against which to test and observe the effects of various ECCM techniques which can be applied to the AN/UPS-1 radar.

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13. ABSTRACT

The AN/GPA-98A countermeasures signals simulator is intended for use with Air Force radars to provide simulated electronic countermeasures signals for radar operator training in an ECM environment. It is capable of simulating two independent aircraft targets with associated ECM -- pulse jamming, chaff, and high duty cycle AM/FM jamming.

The purpose of the study was to determine the modifications to adapt the simulator for use with the AN/UPS-1 air-search radar located at the Naval Postgraduate School radar laboratory. Signals required by the simulator from the radar were determined, the radar and simulator were modified, and interconnections were made. Upon solution of several minor problems, the simulator was aligned and signal levels were adjusted for proper operation with the AN/UPS-1 radar.

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